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ORIGINAL ARTICLE

Role of hydrological factors in shaping water chemistry of small flow-through Polish lake

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Abstract In this study, allometric relations between all parts of lake-catchment systems have been investigated. Inflow and outflow discharges were the main hydrological factors of terrestrial part of the system. Lake water chemistry was presented not simply as ion concentration, but as ion mass accumulated in the lake basin, taking into account the volume of water stored in the lake basin at that time. Redundancy analysis was used to determine the most significant relations between hydrometeorological factors and lake water chemistry. Power of scaling was calculated afterward. The obtained results showed the strongest relations between the following: inflow 2 (I2) and total phosphorus (TP), outflow and magnesium (Mg^{2+}) and chlorides (Cl^{-}), flushing time (Tf) and phosphate (PO_4^{3-}), as well as precipitation (P) and calcium (Ca^{2+})—inverse relation. In most cases, negative allometry was observed. The most stable allometric relations occurred between I2 and TP, the least stable between Tf and PO_4^{3-}. Negative allometry proved a dominant role of hydrological conditions in shaping lake water chemistry. The inverse relationship between P and Ca^{2+} resulted from the fact that Ca^{2+} originated from Cretaceous sediments weathering, not atmospheric input.

Keywords Lake-catchment system · Flow-through lake · Allometry · Water chemistry · Nutrients

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Introduction

Lake-catchment systems are two-dimensional and are composed of terrestrial and aquatic part. Hydrochemical dynamic of a lake catchment area makes up an external load, shaping the direction and intensity of ionic translocation. These processes are consubstantial and affect each other. The power of connections between individual parts of lake-catchment systems subject to the scaling laws and may be presented with allometric theory. For the first time in Polish floodplain lakes, allometry has been used to determine an influence of fluvial impulse on the morphometry of floodplain lakes (Ferencz and Dawidek 2015). Biogens are the most important ions in shaping lakes ecological state (the cause of progressive eutrophication) (Sheffer 1998; Klein and Koelmans 2011). However, hydrological dynamic of a catchment is a driving force of in-lake processes, e.g., flushing time, the degree and rate of ionic transformation (Müller et al. 1998; Lee et al. 2009; Liu et al. 2011). Surface tributaries transport the loads of domestic sewage and agricultural practices shaping the quality of water in a large scale (Ravinda et al. 2003).

Under natural conditions, water quality in small catchment scale is shaped by rocks' susceptibility to the degradation and the time of interaction between water and the host rock (Yidana et al. 2012). Mineral weathering processes determine hydrochemistry of both surface and groundwater in the catchment (Coetsiers and Waltravens 2006; Banoeng-Yakubo et al. 2009). It has been the subject of most hydrochemical analysis in the literature (e.g., Apambire et al. 1997; Abu-Jaber 2001; Wen et al. 2005; Cloutier et al. 2008). Where the residence time is high, the interaction between the rocks and water endures for a long time, leading to a greater degree of interaction that leaches ions into groundwater. Thus, the final quality of the lake water results from the

dissolution of minerals and ion transport to the lake basin, which is its local drainage area. Catchment part represents a dynamic, complex, and long-term process of accumulation of substrates (rock-forming minerals) and then their dissolution and transport to the border of terrestrial part of the system (lakeshore). The value of the ionic load retained in the lake basin is a derivative of the processes of each component of the lake catchment, and the power of this relationship may be presented allometrically.

The proposed study is based on the estimation of allometric relations between different parts of lake-catchment systems. It is a novel approach to the concept of allometry, which is known in the literature. Allometry focuses on the relationship between the selected values characterizing the system. This relationship is also called scaling law. Generally, scaling laws determine how certain measurable properties of the system change, for example, with its linear size (scale). Allometry in the traditional sense—fundamental concept of allometry (the study of size and its consequences)—examines the relationship between the size and shape of organisms and enables to quantify the changes in proportions.

The proposed approach to the research on lake-catchment systems involves a holistic analysis of the processes shaping the water quality, including terrestrial lake catchment area, lake basin, as well as lake outlet. It is known that interactions of bedrock geology, climate, and hydrology influence both groundwater and surface water of the catchment. The aim of the study was to estimate which environmental factor influences which chemical parameter, taking into account both temporal and spatial variability. It is essential in sustainable water management practices.

Study area

Lake Chuteckie (vel Słone) belongs to the so-called Łęczna-Włodawa Lakes, a group of over 70 water bodies, located to the south of the last glaciation boundary. Łęczna-Włodawa Lakes are characterized by small areas and volume of lake basins (the highest Uściwierz's area amounts to 248 ha, the deepest Lake Piaseczno—38 m). Lake Chuteckie is a small water body (lake area, 2.81 ha; volume, 124,370 m^3; maximum depth, 8.1 m) located in the Lublin Upland (Fig. 1). The lake is supplied with two tributaries and drained to the South. The lake basin is surrounded by peat bogs, which are used extensively as pastures.

Methods

Hydrometeorological measurements

All the field measurements were carried out from April 2009 to October 2010. Regular readings of lake and stream water stages from electronic staff gauges were done everyday at 7 a.m. According to Smidth (2002) and Pappenberger et al. (2006), the errors of water level measurements are very small (1–2 cm). Flow rate measurements were taken once a month using Nautilus 2000 or Velaport 801 electromagnetic flow meters. The current meters have a measuring range of 2.5 m s^{-1} and zero with an error of ± 2 mm s^{-1}. The degree of error amounts to 1 % of the range. Flow sensors were calibrated according to the recommended specifications of the manufacturers. Daily discharges of lake inflows and outflows were determined from a rating curve of each cross section. FRIEND procedure (Flow Regimes from International Experimental and Network Data) was used for a hydrograph division (to surface and underground inflow and outflow).

The algorithm was prepared by the Institute of Hydrology, Wallingford (United Kingdom), as part of the international cooperation International Hydrological Program (IHP) UNESCO. The calculating procedure was based on the construction of pentads periods, in which the minimum values of flow had to fulfill the $Qmin_{i-1} > 0.9\ Qmin_i > Qmin_{i+1}$ condition. The points selected this way created a line that reflected the underground flow (base flow). Daily underground flow ratio was obtained. An algorithm used in this study reflected dynamics of the underground water outflow, especially during the periods of increasing water levels. Groundwater inflow 1 (GI1) has been obtained due to a hydrograph of inflow 1 division, while groundwater inflow 2 (GI2) resulted from a division of a hydrograph of inflow 2.

The flushing time was calculated using the equation:

$$\mathrm{Tf} = Q \times V^{-1} \quad (1)$$

where Tf flushing time, Q daily underground outlet, V daily lake volume.

Daily sums of precipitation were calculated using Hellman pluviometer with reception surface 200 cm^2. Measurements were taken once a day, at 7.00 UTC. Using Sonel echo-sounder and GPS Garmin receiver, bathymetric measurements were performed once a season. Points were then imported into ArcView software and then plotted on calibrated topographic maps 1:10,000. IDW interpolation method was performed in order to draw bathymetric sketches. Weekly volume of lake basin was calculated on the basis of bathymetric maps.

Chemical methods

Water samples of inlets, lake, and outlet ($n = 96$) for chemical analysis were collected bimonthly. Using LF300 Fotometer, concentration of Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, Cl^-, TP, PO_4^{3-}, TN, NH_4^+, NO_3^-, NO_2^-, SO_4^{2-}, and total

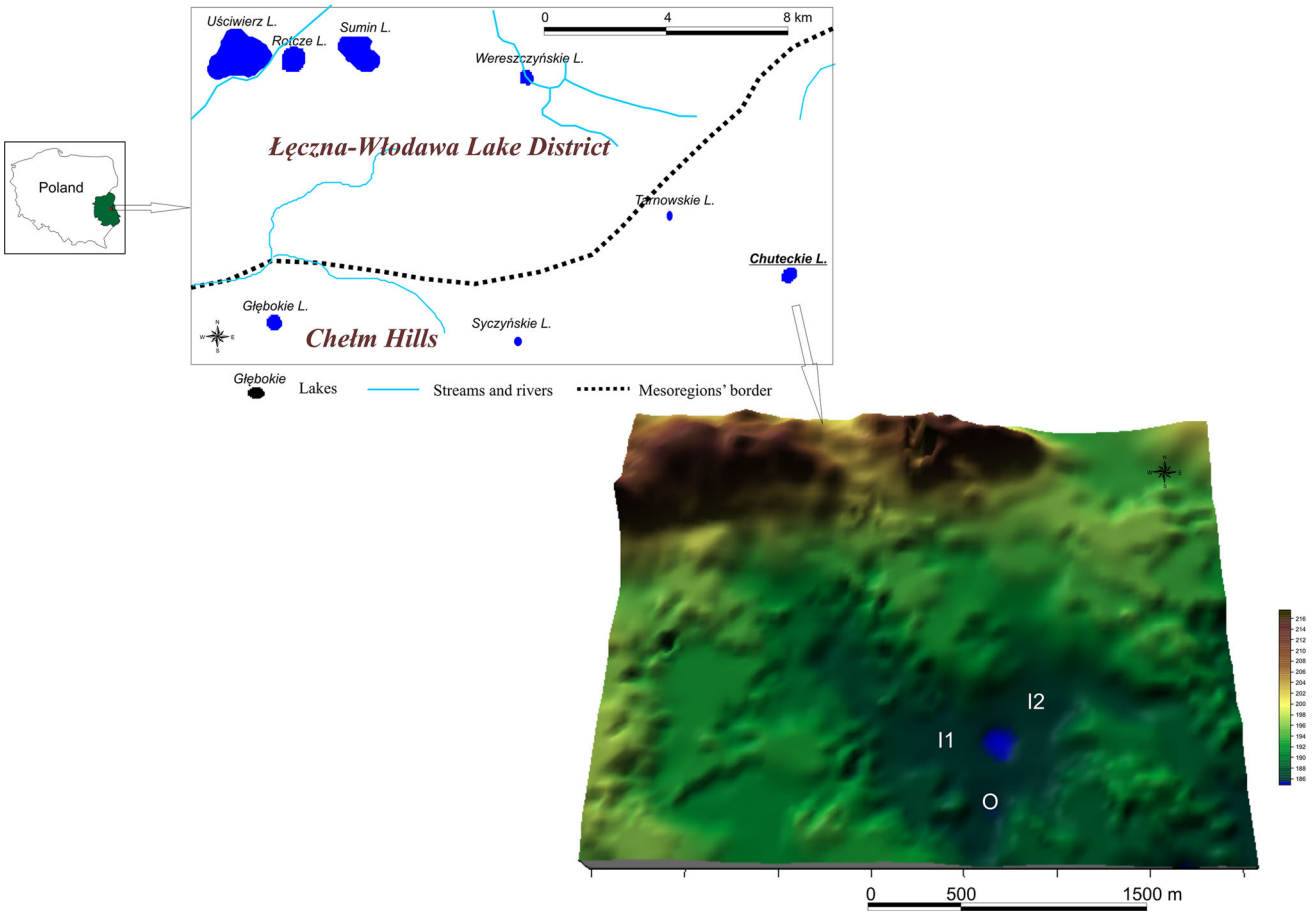

Fig. 1 Location of the lake-catchment system under study

hardness was measured. Measurements were taken in situ in the deepest part of the Lake Chuteckie. Taking into account the volume of water stored in the lake basin at the day of sampling, the temporary ionic concentrations (mg L^{-1}) were converted to total mass (kg) of particular ion accumulated in the lake basin.

The ionic load of the streams was calculated as follows:

$$L = CQ \tag{2}$$

where L load (kg year), C ion concentration (mg dm^{-3}), Q discharge (dm^3 s^{-1}).

A mass balance of the lake (L_L) was calculated as a difference between the load entering and those that exits the lake basin (Eq. 3)

$$L_L = (LI1 + LI2) - LO \tag{3}$$

where LI1, ionic load transported by the first inflow; LI2, ionic load transported by the second inflow; LO, ionic load transported by the outflow.

Statistical analysis

Ordination techniques were used to demonstrate relationships between hydrological variables: total inflow 1 (I1), inflow 2 (I2), outflow (O), groundwater inflow 1 (GI1), groundwater inflow 2 (GI2), flushing time (Tf), and the chemical ones. An indirect multivariate detrended correspondence analysis DCA method was used to calculate gradient indicated by chemical variables. The length of the gradient was <3 standard deviation; thus, RDA analysis was used to find the strongest relations among hydrometeorological and chemical data. Automatic forward selection of hydrometeorological variables, Monte Carlo permutation test were performed (999 permutations) to determine the most important variables (significance must have exceeded 0.05).

Allometric relations of the highest correlated variables have been quantified using Eq. 4.

$$Y = aX^b \tag{4}$$

The function is the basis of the concept of hydraulic geometry (Bull 1975; Park 1978) and has been widely used in geomorphological literature (Hood 2007; Evans 2012).

An exponent value is crucial from the point of view of allometric analysis, the sign and magnitude of which reflect the rate of change of a dependent variable Y in relation to changes in the independent variable X. After the transformation of Eq. 4, the exponent b will be calculated as follows:

$$b = \frac{(\ln Y_2 - \ln Y_1)}{(\ln X_2 - \ln X_1)}, \quad (5)$$

where X_1, X_2, Y_1, and Y_2 are system variables of the two time steps.

This equation, assuming a constant b value, expresses the relation of the dependent variable change with respect to a fixed rate of change of the independent variable. If $0 < b < 1$, the independent variable X has more significant changes than the dependent variable Y. If $b > 1$, the dependent variable is characterized by more rapid changes than the independent variable X. Accordingly, the first case of this relationship is defined as negative allometry and the second as a positive one (Bull 1975). If $b = 1$, the rate of changes of both independent and dependent variables is the same, and allometry is defined as isometric. The exponent sign "+" indicates a directly proportional relation of the variables (convexity of the function), and "−" indicates a relation of inverse proportion (concavity of the function).

Results

Precipitation showed distinct variability in both years under study. In nine observed months of 2009, almost equal quantity of precipitation occurred than in 12 months of 2010. Very high sums of precipitation (higher than 60 mm) were observed from May to August 2009 (Fig. 2).

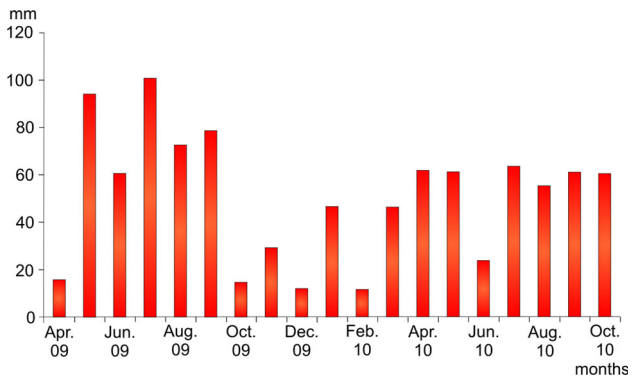

Fig. 2 Distribution of precipitation during the study period

Concentrations of major ions (Ca^{2+}, HCO_3^-, Mg^{2+}, Cl^-, SO_4^{2-}) showed very similar fluctuations in waters of both tributaries. Calcium showed the highest inter-annual stability. The lowest concentration of Ca^{2+} in inflow 1 and inflow 2 waters was observed in April (110 and 108 mg L^{-1}, respectively), whereas the highest in September (176 and 167 mg L^{-1}, respectively). A similar trend occurred with reference to HCO_3^-, whose concentration varied from 302 and 317 mg L^{-1} in April, respectively, to 465, 448 mg L^{-1} in September. Both Cl^- and SO_4^{2-} showed high and multidirectional variability. The highest concentration of chlorides was observed in winter (23.4 mg L^{-1} in I1; 19.1 mg L^{-1} in I2) (Table 1). Biogens showed the highest concentration in winter.

With regard to the Ca concentration, lake waters showed very stable conditions. The lowest values occurred in spring (120 mg L^{-1} in April and May) and the highest in summer (131 mg L^{-1} in June). HCO_3 concentration showed no seasonal trend, with concentration amounting from 312 to 348 mg L^{-1}. The highest concentration of chlorides, similar to the inlet waters, was observed in winter, i.e., 19.5 mg L^{-1}. NO_3^- showed the highest concentration in the lake waters among the measured biogens. Generally, biogens showed the highest concentration in winter, but in other seasons, there has not been a clear fluctuation pattern.

Concentration of major ions in water of outflow was less stable than in inflow. Ca^{2+} concentration amounted from 81 mg L^{-1} in September to 112 mg L^{-1} in April, HCO_3^- from 213 to 304 mg L^{-1}, respectively. SO_4^{2-} showed both the highest and the lowest concentrations in April 2009 and 2010. The biogen values were the highest in May in the outlet water and the lowest in April, during the meltdown.

Flow rates showed both spatial and temporal variability. The highest values were observed in winter (4.69–118.21 L s^{-1}), while the lowest occurred in summer (0.29–50.86 L s^{-1}) in each stream (Table 1). Flow rates presented a pattern: outflow > inflow 2 > inflow 1. The same pattern was observed in groundwater recharge. Based on Ferencz and Dawidek's (2014) results and the results confirmed by this study, groundwater supply amounts to circa about 15–20 % of lake input via tributaries. The lake is permanently recharged by the aquifer.

The total range of values of obtained ionic load in almost all cases (except NH_4^+ load) was found to be the greatest in outflow. Quartile range of total phosphorus (TP) and NH_4^+ (except outlet) showed a significant negative skewness (Fig. 3). A close to normal distribution was recorded in case of NO_3^- in each stream and PO_4^{3-} in inflows. The average values of NH_4^+ and NO_3^- were an order of magnitude higher than loads of PO_4^{3-} and TP (Fig. 3). The highest dispersion of load values was observed in relation to NH_4^+ in both inflows. A proportion of maximum to minimum values exceeded 220 in I1 and

Table 1 Hydrochemical characteristic of Lake Chuteckie, its tributaries, and outflow

	Inflow 1			Inflow 2			Lake			Outflow		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Concentration (mg L^{-1})												
Ca^{2+}	107.7	176.9	128.9	108.2	166.9	128.1	120.5	130.7	124.2	112.4	136.9	122.7
Mg^{2+}	0.1	3.0	1.3	0.2	8.8	3.4	0.2	4.5	2.1	0.7	26.1	7.4
HCO_3^-	283.4	465.1	356.3	310.5	419.1	341.5	312.4	356.3	333.5	307.5	236.3	334.1
Cl^-	2.8	23.4	7.9	2.8	19.1	7.3	3.2	19.5	7.8	3.2	17.4	7.4
SO_4^{2-}	4.8	39.7	24.1	12.0	40.2	25.0	22.6	43.2	32.2	2.9	49.0	26.9
NO_3^-	0.1	2.8	1.5	1.1	7.0	3.0	0.0	3.5	1.6	0.4	3.4	1.7
PO_4^{3-}	0.001	0.2	0.1	0.0	2.2	0.4	0.008	0.4	0.1	0.02	0.4	0.1
TP	0.01	0.5	0.2	0.006	0.4	0.1	0.006	0.4	0.1	0.01	0.3	0.1
Discharge (L s^{-1})												
Spring	2.47	72.84	24.92	3.40	118.21	116.38				6.17	116.38	43.95
Summer	0.29	28.06	4.75	0.37	43.49	50.86				0.98	50.86	10.19
Autumn	2.45	36.35	8.14	3.38	56.35	12.12				6.14	63.03	16.61
Winter	4.69	72.84	19.58	6.67	118.21	30.56				10.77	116.38	34.19

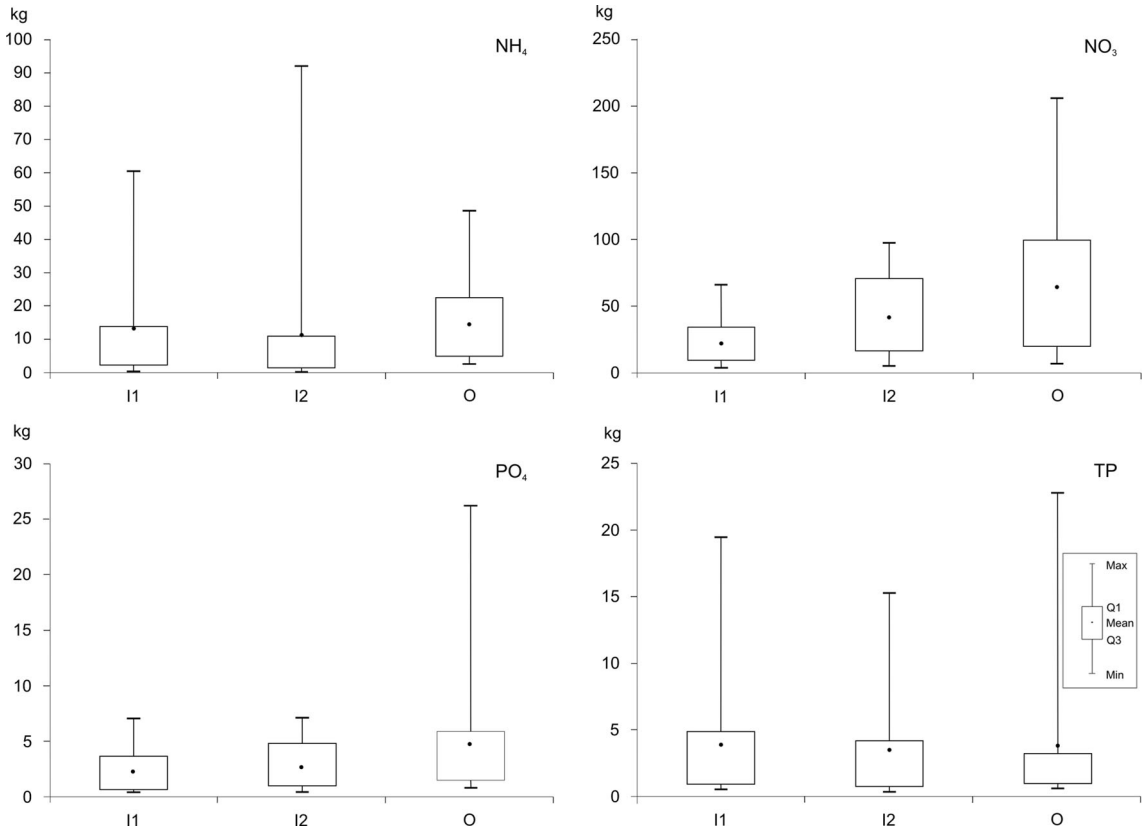

Fig. 3 Values of ionic load carried by inflows and outflow (kg)

660 in I2. Multi-annual variability of ionic load on the transect inflow–inflow was observed. Only NH_4^+ for most of the year showed the pattern I1 > O > I2; in case of other ions, changes were fast and multidirectional.

Chemical mass balance of the lake showed great variability. No similarity in the distribution of NH_4^+, NO_3^-, PO_4^{3-}, and TP was observed. Values of NO_3^- mass balance ranged from −13.5 kg in October 2010 to 90.6 kg in

Table 2 Selected statistical parameters of a chemical mass balance of the Lake Chuteckie (kg)

Key statistics	NH_4^+	NO_3^-	PO_4^{3-}	TP
Mean	9.99	−0.84	0.14	3.58
Standard error	5.18	7.73	0.84	1.42
Median	3.79	7.88	0.20	1.42
SD	22.60	33.68	3.68	6.21
Sample variance	510.69	1134.66	13.53	38.52
Kurtosis	9.24	0.71	6.56	5.38
Skewness	2.75	−1.10	−1.99	2.15
Range	104.07	130.08	18.12	25.23

April 2009 (Table 2). The mass balance of NO_3^- showed positive values from the beginning of the observation period to February 2010, as well as in summer 2010. The values amounted from −83 kg in April 2010 to 47 kg in October 2010. The mass balance of PO_4^{3-} showed the lowest variability in the study period (Table 2). The values ranged from −12 kg in May 2010 to 6 kg in June 2009. Negative values, similar to TP, were observed mostly in summer 2010. Lake's mass balance of TP varied from −1.6 kg in May 2010 to 23 kg in June 2009. In 2009, ionic input was significantly higher in both PO_4^{3-} and TP than in 2010.

RDA analysis was performed to specify direct relationships between chemical and hydrometeorological variables. All chemical variables explained 51.6 % of the total variance. However, variables that significantly explained the variance in water chemistry were precipitation ($\lambda = 0.26$; $F = 5.96$; $p = 0.014$) and flushing time ($\lambda = 0.15$; $F = 4.48$; $p = 0.030$). Generally, inflow (I1, I2) showed significant positive correlation with total phosphorus (TP), $r = 0.54$, $p \leq 0.05$ and $r = 0.56$, $p \leq 0.05$, respectively (Fig. 4). Flushing time correlated positively with PO_4^{3-} ($r = 0.81$, $p \leq 0.05$). A mass of major ions: Cl^- and Mg^{2+} were dependent on outlet $r = 0.55$, $p \leq 0.05$ and $r = 0.69$, $p \leq 0.05$, respectively. Ca^{2+} showed a strong negative correlation with precipitation ($r = -0.73$, $p \leq 0.01$). RDA allowed to determine the strongest relationships between hydrometeorological parameters and ionic load accumulated in the lake basin. Volatility of allometric relationships in the study period was calculated for: (a) I2 and TP, (b) O and Mg^{2+}, (c) O and Cl^-, (d) Tf and PO_4^{3-}, and (e) P and Ca^{2+}.

For all dependencies, negative allometry was observed in most cases (Table 3). Usually in August (I2 and TP, O and Mg^{2+}, and Tf and PO_4^{3-} relationships) or in December (O and Mg^{2+}, O and Cl^-, and Tf and PO_4^{3-}, P and Ca^{2+} relationships), positive allometry occurred for each of the analyzed dependence. It was, however, episodic in nature. Periods of rapid changes of allometric exponents were observed. The more visible was April 2009, when

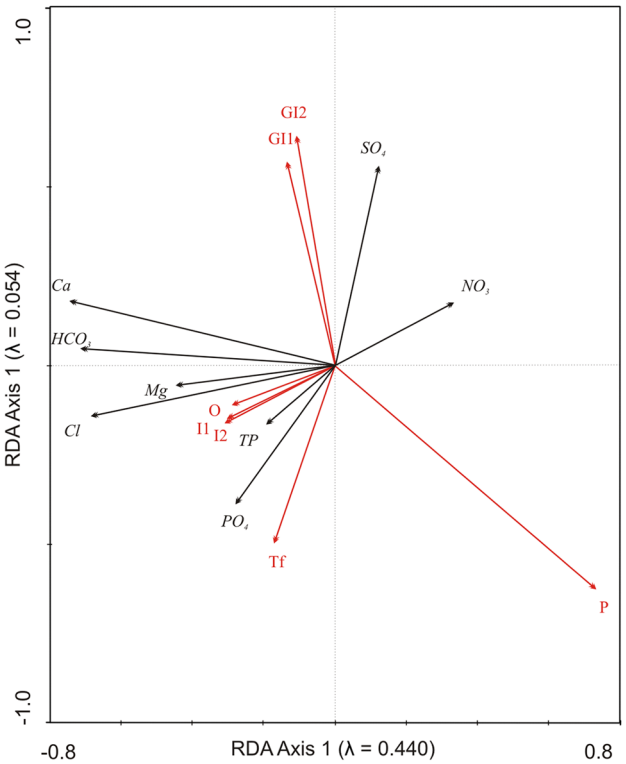

Fig. 4 Redundancy analysis (RDA) biplot showing chemical and hydrometeorological variables

allometric exponent in all case was higher than 1 (positive allometry). Next period of rapid changes occurred in August 2009 (I2 and TP, O and Mg^{2+}, and Tf and PO_4^{3-}), 2010 (Tf and PO_4^{3-}), and November or December 2010. The most stable negative allometry conditions were noted in the case of relationship of I2 and TP, whereas the least stable characterized the relationship of flushing time and PO_4^{3-}. Allometric exponents' distribution showed negative skewness. The greatest value of the interquartile range was observed for relations with calcium and precipitation. In this case, the highest mean value 0.58 was also observed.

Discussion

In terms of Polish lakes, the role of hydrology in water and chemical cycling is poorly elucidated (Klimaszyk and Rzymski 2013). The role of hydrological impulses in shaping water chemistry of lake-catchment systems in terms of Łęczna−Włodawa Lakes is even less known. The results showed that the concentration of measured ions varied seasonally. It has been confirmed in other lakes of the region (Adamczuk et al. 2015a, b). A clear domination of bicarbonate and calcium ions resulted from geological structure of the region and abundance of Cretaceous sediments in the bed rock (Wach 2005; Peczula et al. 2014).

Table 3 Values of allometric exponents of calculated relationships

	Allometric relations				
	I2 and TP	O and Mg^{2+}	O and Cl^{-}	Tf and PO_4^{3-}	P and Mg^{2+}
Apr 2009	1.00	2.00	3.00	4.00	5.00
May 2009	−0.57	6.29	0.17	0.30	−0.03
Jun 2009	0.01	0.02	0.02	−0.03	−0.02
Jul 2009	0.01	0.01	0.01	−0.05	−0.01
Aug 2009	−1.42	−5.16	−0.31	1.32	0.02
Sep 2009	−0.02	0.10	−0.12	0.44	0.41
Oct 2009	0.16	0.02	0.02	−0.35	0.01
Nov 2009	−0.57	0.84	−0.28	2.09	0.05
Dec 2009	0.02	−2.68	3.92	0.64	−0.03
Jan 2010	0.02	0.02	0.02	−0.03	0.02
Feb 2010	0.02	0.02	0.02	−0.03	0.02
Mar 2010	−0.42	0.22	−1.00	−0.02	−0.02
Apr 2010	0.03	0.04	0.04	−0.02	−0.04
May 2010	0.19	0.10	0.10	−0.01	0.10
Jun 2010	−0.32	−0.58	−0.53	1.26	−0.03
Jul 2010	0.00	0.02	0.02	−0.02	−0.02
Aug 2010	0.13	−0.81	−0.62	5.00	0.29
Sep 2010	−0.01	−0.01	−0.01	−0.01	0.04
Oct 2010	0.02	0.02	0.02	−0.03	−2.41

Ferencz and Dawidek (2014) presented the duality of Lake Chuteckie catchment in terms of geological structure. The surrounding vicinity of the lake is formed of organogenic sediments (mostly peat bogs), while the upper catchment parts were made of carbonate rocks. Thus, high runoff and groundwater recharge from Cretaceous aquifer and predominance of carbonate−calcium waters determine good lake water quality compared to other lakes located in Lublin Upland Region: Lake Syczyńskie, Lake Tarnowskie, and Lake Pniówno. The prevalence of hydrological outflow role (higher discharge than in inflowing streams) was observed in other Łęczna−Włodawa lakes by Dawidek and Ferencz (2014). They identified the fact with deepest lakes, where high groundwater recharge is observed. Thermic profile in water column of Lake Chuteckie (data not presented) confirmed high input of groundwater to the lake basin. The results showed significant role of NH_4^+ and NO_3^- in shaping lake water chemistry. The most stable condition of ionic translocation was observed for NH_4^+ in inflow waters. Values of mass balance of the lake basin showed the dependence from atmospheric precipitation. Positive values of ionic inlets and outlet differences were observed in periods of intensive atmospheric supply and snow meltdown. Negative values were typical for summer, which is typical and results from high primary production and biogen consumption in lake waters (Adamczuk et al. 2015b).

Pęczuła et al. (2014) established ecological state of Chuteckie Lake as high, on the basis of chlorophyll *a*, transparency, conductivity and total phosphorus. It is typically not observed in catchment with prevailing agricultural land use (Jordan et al. 1997; Williams et al. 2005; Smal et al. 2005). Although arable lands amounted to 60 % of the lake catchment, extensive agriculture influenced very little lake water quality. Similar relation was observed by Smal et al. (2005) in Lake Rotcze where, although agricultural lands and meadows and pastures took up 80 % of the catchment, advanced development of submerged macrophytes was observed (Kornijów et al. 2002; Lorens and Sugier 2010). Contrary to the results of Shin et al. (2013), the dissolved ion concentration in Lake Chuteckie catchment was higher in the upper part of the catchment than in the lower part. It indicated the important role of lake basin in ionic retention, which has also been stated by Dawidek et al. (2009) in other small Łęczna−Włodawa Lake (Lake Syczyńskie).

The prevalence of negative allometry indicated the dominance of hydrometeorological factors in shaping water quality of Lake Chuteckie; it results in high stability of geological ions, calcium, and bicarbonate and has been previously observed in other basins located in the southern part of the Łęczna−Włodawa Lakes region (Dawidek 2002). Similar to Lakes Sumin, Rotcze, and Syczyńskie, Lake Chuteckie showed high annual variability of Mg^{2+} and Cl^{2+} concentration and significant influence of inlets'

role in shaping lake water quality (Ferencz et al. 2014). A strong inverse relationship of Ca^{2+} and precipitation resulted from chemical feature of precipitation, in which Janiec (1999) assessed calcium concentration as 30 mg L^{-1}, as well as the fact that precipitation maxima in the region are observed in summer, when groundwater recharge from Cretaceous sediments is very low. The period when high groundwater inflow is observed is winter, a season of low atmospheric precipitation. A stable and strong relationship of inlet and TP is in line with the results of Smal et al. (2005) for the shallow Łęczna–Włodawa lakes. Allometric relationship of Tf and PO_4^{3-} pointed to the high role of water exchange in the biogen mass accumulated in the lake waters. Therefore, instability stemmed from the high rate of seasonal variation of Tf (Ferencz and Dawidek 2014) and high variability of PO_4^{3-}. Periods of rapid changes of the values of allometric exponents corresponded with meteorological conditions. After the low quantity of precipitation in February and March 2009, groundwater recharge prevailed in shaping lake water quality (leaching processes). Thus, allometric exponents showed more rapid changes of chemical parameter than in hydrological one. Similar situation occurred in August 2010. Less significant changes of hydrological variables than chemical ones observed in summer resulted from biological processes and biogens accumulation by aquatic organisms (Li et al. 2016).

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